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Overview of Automobile Navigation Systems and Potential Applications

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Abstract:	Integrated automobile navigation systems blending various combinations of radio location, dead-reckoning, cartographic and computer technologies are emerging which will have significant, but as yet largely unexplored, impacts on roadway transportation systems. A self-contained navigation system based on a digitized map is already commercially available and it is expected that systems now under development by most of the automobile manufacturers will be widely available as showroom options by the end of the decade. This paper gives an overview of both the technology and potential applications of these systems. The various types of automobile navigation systems are discussed, including dead-reckoning systems and those based on electronic sign posts, Loran C and satellites for positional information. On-board computer, data storage and display technology are also discussed, as well as human factor considerations. A wide range of applications can be visualized. For autonomous systems, route following will be the principal function, which can be used to advantage by trucks and emergency vehicles as well as by the private motorist. For systems where data communications is possible between vehicles and a roadside unit or a control center, dynamic route guidance and traffic management are possibilities. The various classes of systems are defined and their functional capabilities identified. Examples of past, present, and future systems are given.
Key words:	vehicle navigation, route guidance, traffic management
Comments:	This paper is intended to be an overview of the relevant technology and applications and does not treat any area or system in great detail.
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OVERVIEW OF AUTOMOBILE NAVIGATION SYSTEMS AND POTENTIAL APPLICATIONS

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INTRODUCTION

The microelectronics revolution has now reached the automobile. Practically every on-board function will soon be monitored and/or controlled in one way or another by a microprocessor, and the traditional electro-mechanical gauges and dials are quickly being replaced by multi-function solid state displays. Not only will the automobile of the 90's have an on-board computer rivalling that of a minicomputer of only a few years ago, but it seems highly likely that it will also have access to prodigious amounts of on-board information stored in a laser compact disc, bubble memory or similar device.

Advancing technology in other areas will also find automotive applications. Speech synthesis and recognition, holographic displays, fiber optics and other seemingly exotic technologies are all being considered, and recent advances in data cellular mobile radio will provide 2-way communications with the automobile. Together, these developments are setting the stage for the development of a 'mobile information system' which can carry out a variety of useful functions to expand the capabilities of the modern automobile while at the same time enhancing its safety and efficiency as a transportation mode.

Science fiction? Perhaps, but the rapidly falling cost of microelectronics and the other high-tech components strongly suggests that a market could develop for such products provided the consumer perceives that they will serve a useful purpose (1). In-vehicle navigation systems are certainly no exception, and it is the purpose of this paper to briefly examine the status of this technology and speculate on the potential applications.

NAVIGATION TECHNIQUES

Navigation is the process used to determine a vehicle's course as it moves from one place to another, and has been used for centuries by ships travelling at sea. The techniques have since become highly developed for both sea and air navigation purposes, but it is only recently that they have been seriously applied to the navigation of land vehicles for both military and non-military applications. Military systems involve the navigation of freely manoeuvrable robot vehicles and require sophisticated, expensive technology. In contrast, non-military systems, which are mainly used for the navigation of roadway vehicles, are considerably simpler because the movement of the vehicle is constrained to the roadway network.

The measurement of position is obviously essential for navigation. However, since it is very difficult in practice to measure one's absolute position continuously, virtually all navigation systems use dead reckoning to keep track of the course of the vehicle between position measurements.

Dead Reckoning Navigation

Dead reckoning establishes vehicle postion by keeping account of the distance and direction travelled from a known starting position. It is thus a "position keeping" rather that a "position finding" technology, and must be periodically up-dated to eliminate the intrinsic cumulative errors due to imperfections in the dead reckoning sensor hardware. The most common sensors used for determining distance and direction (heading) for dead reckoning navigation (2) are summarized in TABLE I.

Device	Distance	Direction
Odometer	x	
Differential Odometer	x	x
Gyrocompass		x
Magnetic Compass		x
Yaw Rate Sensor		x

TABLE I Dead Reckoning Navigation Sensors

The odometer is the commonest means for measuring distance. When used on opposite wheels on an axle, it can also be used to measure changes in heading since the difference in wheel rotation is proportional to the change in direction of the vehicle, even when the path is irregular - hence the term "differential odometer". The accuracy of the odometer is limited by variations in wheel diameter with tire pressure. Inertial navigation systems can also be used for automobile navigation, but their cost is prohibitive except for special applications.

The simple magnetic compass has been used for some time on automobiles as a means of measuring direction, but it is notoriously unreliable because of the heading-dependent distortions in the Earth's magnetic field caused by the presence of the vehicle. It has been largely replaced by the flux-gate compass which can be compensated to minimize the effect of such distortions. *Changes* in direction (or yaw angle) can be determined by integrating the output of a yaw rate sensor, typically a conventional rate gyro, but new inertial sensors are under development which promise to be simpler and less costly (3). The gyrocompass, which was used for navigation of the Lunar Roving Vehicle (LRV) on the moon, is not used on any current systems but has promise for the future.

Determination of Position

Position determining techniques which are suitable for automobile navigation applications are summarized in TABLE II. Typically these would be used in conjunction with a dead reckoning system to periodically provide a position "fix" to remove cumulative build-up of position error.

Radio Frequency Trilateration. This technique depends on the measurement of the difference in the arrival times of synchronized timing pulses received from at least three different ground- or satellite-based RF transmitters. These can be used to calculate vehicle position. Loran (LOng RAnge Navigation) is a low frequency ground-based system used around the world by ships and aircraft. It has had limited application on land due to noise and other problems, but the development of improved receivers and the recent appearance on the market of low-cost Loran C microprocessor chips may make it viable in the future. Accuracy is limited to about 200 meters. The Navstar GPS (Global Positioning System) being established for the U.S. Department of Defense will eventually have a total of 18 satellites from which position can be estimated (for military purposes) to within 15 meters

in three dimensions anywhere in the world. For civilian applications, the accuracy will be 100 meters and the service is expected to free. This system is the basis for several automobile navigation systems now under development.

Proximity Beacons. This technique depends on the receipt of a location-coded signal from a roadside transmitter to determine vehicle position. Distributed throughout the roadway network (typically at major roadway intersections), these beacons provide an electronic signpost for the vehicle to up-date its position as it passes by. Transmission of the signal is usually by low-powered radio but infrared systems are also being used. As will be described later, an extension of this technique to include two-way communications between the roadside and a vehicle equipped with a suitable transceiver, creates the possibility for dynamic route guidance and other types of interactive control.

Map-Matching. This technique is based on the fact that roadway vehicles are essentially constrained to travel on the roadway network. This makes it possible to use a map as the basis for matching the pattern of the vehicle's indicated path (from dead reckoning) with that of the vehicle path on the map, and so determine vehicle position at specific points where the pattern clearly changes, such as at a turn in the road. The map-matching process uses pattern recognition techniques derived from the field of artificial intelligence and, depending on the accuracy of the digitized map data base, is capable of determining vehicle position with very high accuracy (4). Since it now appears feasible to store very large data bases in the vehicle (by means of a compact disc or other type of read-only memory), a vehicle navigation system combining dead reckoning with map-matching is an attractive option, and indeed is the basis for several new systems. It is the only configuration which does not depend on the availablility of outside information when in operation. It does, however, depend critically on the accuracy of the stored digitized map data base.

Radio Frequency Trilateration

- Ground-based - Loran C
- Satellite Systems - GPS, Transit

Proximity Beacons

- Radio
- Infrared

Map-Matching

- Digitized maps in CD or bubble ROM
- Pattern recognition

TABLE II Position Determining Techniques

VEHICLE NAVIGATION SYSTEMS

Early Systems

The possibility of providing improved routing information for the driver was the impetus for the development of a number of experimental in-vehicle route guidance systems in the 1960's and early 1970's. These systems did not provide an in-vehicle navigation capability as such, but they are nevertheless interesting because they depended on communications

with roadside units (proximity beacons) at various locations throughout the network to determine vehicle position.

Two pioneering systems were developed in the United States during the 60's, but both systems were really ahead of their time and did not proceed beyond the experimental stage. The first was the Driver Aid, Information and Routing (DAIR) System developed by General Motors Corporation (5). This system used various arrangements of magnets in the roadway to identify specific locations throughout the network.

The other system was the Electronic Route Guidance System (ERGS) developed for the U.S. Bureau of Public Roads (6), which was the first system with a two-way communications link between the vehicle and the roadside. Each vehicle carried a display console into which the driver entered his destination, which was relayed to the various roadside units which the vehicle passed as it moved though the network. The roadside units each responded with appropriate routing instructions, which were displayed on the console in the form of an arrow indicating the direction to be followed (i.e. right turn, bear left, straight ahead, etc.). ERGS provided static route guidance over the "best" path based on pre-programmed historical routes, and was being enhanced to include dynamic route guidance (traffic-responsive routing) when the project was cancelled in the late 1960's because of the projected high cost of the infrastructure which would be required for implementation.

A wide variety of roadside-based systems were developed during the 1970's, but few have survived beyond the experimental stage. Most used only one-way communications from the roadside to the vehicle, but the German ALI (8) and the Japanese CACS (9), both used two-way communications and were similar in many other respects to ERGS. They were both involved in extensive field evaluations. In fact, an up-dated version of CACS is still being evaluated in Tokyo, with real-time dynamic route guidance as the ultimate goal (9). As was the case for the earlier systems, these systems require an expensive roadside infrastructure for their operation, and are limited in application to areas where such an infrastruture is in place.

Autonomous Systems

A new generation of systems have been under development since the early 1980's by the major car manufacturers and a few electronics companies. The goal is to market these systems as showroom options or after-market accessories by the end of this decade (1,7).

These systems blend various combinations of navigation technologies together to form an autonomous, or self-contained, in-vehicle navigation system. They differ from earlier systems in that the cost of the system is born entirely by the user since a roadside infrastructure is not required. Virtually all the systems are based on electronic maps of one type or another (but not necessarily using map-matching), and are thus limited in application by map coverage. A summary of the characteristics of typical types of systems, either already existing or under development, is given in TABLE III.

This table, which makes no pretence to be completely accurate, illustrates the range of technologies which are being used in the development of these systems. Each one has its stengths and weaknesses in terms of performance, cost and potential marketability.

The satellite-based systems may be some time in coming due to the set-back in the U.S. space program; all 18 GPS satellites (which are necessary for 24 hour coverage) were to have been in orbit by 1988, but this will probably now be delayed until well into the next decade. On the other hand, the map-matching systems depend on the availability of

accurate maps which can be digitized to generate the necessary map data base; these are scarce, and the digitizing process can be expensive and time-consuming. In addition, since the road network changes over time, there are problems with keeping the map data base current.

SYSTEM	DEAD RECKONING	POSITION	DISPLAY	MAP
Honda Gyro-Cator	He rate gyro + odometer	Manual adj. at known pt.	CRT	Transpar. overlay
Nissan Driver Guide	Mag. compass + odometer	Manual adj. at known pt.	Fluoresc. tube	None- 10 km max. range
Daimler-Benz Routenrechner	"	Manual adj. at known pt.	LCD	Hwy map in ROM
Omni Devices Navigator	"	?	LCD/fiber optics	Film cartridge
Chrysler CLASS System	Differential odometer	Navstar GPS	Touch screen CRT	Video disc image of map
Ford	Mag. compass + odometer	Transit	CRT	"
GMC (a)	"	Loran C + GPS	CRT	"
Etak Navigator + GMC (b)	Mag. compass + diff. odometer	Map-matching	CRT	Digitally encoded map on mag. tape
Blaupunkt EVA	Differential odometer	Map-matching	LCD	Digitally encoded map on comp. disc

TABLE III Commercial Automobile Navigation Systems

The various systems reflect the three basic methods of storing the map information – photographic, digital image and digital encoded. Honda and Omni use photographic storage, which is the least sophisticated of the methods. Honda requires the user to slip a transparent map overlay over the CRT, while Omni stores maps on film and uses a fiber-optics/LCD array to display the map. Chrysler, Ford and GMC (a) use the second method. The digital encoding method is the most sophisicated, and entails digitally encoding the map as a set of internodal vectors defining each roadway and intersection, and is used by Daimler-Benz, Etak and Blaupunkt.

Probably the most promising system developed so far is the Etak Navigator, which was the first commercially available system using map-matching technology. As indicated in TABLE III, the system uses a flux-gate magnetic compass as well as a differential odometer for dead reckoning input, and uses tape cassettes to store the digital map data. The system continuously displays the vehicle's location relative to its surroundings on a

CRT map. A stationary arrowhead in the center of the CRT represents the vehicle position, and points to the top of the screen indicating the direction the vehicle is travelling. As the vehicle travels, the map rotates and shifts about the arrowhead so that the map always presents the same view of the roadway as the driver sees ahead of his vehicle. General Motors has apparently bought exclusive North American rights to Etak technology - GMC (b).

Similar systems are being developed elsewhere, and it would appear that this particular approach has the greatest potential for the future, particularly in view of the coming availability of the CD ROM for storage of massive map data bases. A single CD ROM can store over 500 megabytes of information, which is enough capacity to store a digital map of every highway and street in Canada and the U.S.

Proximity Systems

There are a number of proximity beacon type systems under development which are noteworthy. The ALI-SCOUT system (11) being developed jointly by Bosch/Blaupunkt and Siemens is particularly interesting because it combines a dead reckoning navigator with a two-way infrared communications link between the vehicle and the roadside. The high bandwidth of the infrared link allows the transfer of large amounts of data within a short period of time. ALI-SCOUT is based on the original ALI system (8) and Siemens AUTO-SCOUT, which has recently been evaluated in W. Berlin. It is a route guidance and driver information system. Instead of storing a map within the vehicle, a digitally encoded map of the entire surrounding area is fed to each vehicle as it passes a beacon, including traffic dependent guidance recommendations. Knowing its position and the driver's destination, the vehicle navigation system can then guide the driver over the most expedient route to his destination.

As mentioned earlier, the Japanese are continuing to develop their CACS (Comprehensive Automobile Control System) for application around Tokyo and other large congested urban areas in Japan (9).

The high cost of the this type of system, which requires specially equipped vehicles and an extensive roadside infrastructure, would have to be largely borne by public agencies and is thus most cost-effective in large urban areas.

Human Factors Considerations

All of the systems which have been desrcibed depend on a visual display of one type or another to convey information to the driver. Most of the map-based systems use a CRT display which is mounted to be within easy view of the driver. The route guidance systems provide a LCD or similar display to convey routing instructions to the driver. This has raised serious concerns about the ability of the driver to maintain safe control of the vehicle when trying to read these displays while in motion. There is not yet enough experience with these systems to indicate whether or not this is a problem, but it seems obvious that human factors considerations will have to play a major role in the design of future systems. Already, there are various types of holographic head-up displays under development which will allow the driver to view information without taking his eyes off the road. Voice-synthesis is another technology being explored as a means to convey information to the driver without interfering with the driving task.

There is also the requirement for entering information into the system, such as present position and destination. Touch-screen CRT's are replacing keyboards and various button arrangements for this purpose, but there is a trend toward consolidating all vehicle input

and output devices into an integrated "message center" using flexible format displays. It would thus make sense for cost and ergonomic reasons to ultimately integrate navigation and route guidance displays into the vehicle message center.

APPLICATIONS

Autonomous Navigation Systems

The benefits which might be derived from providing the driver with improved routing information have been studied in many countries. In Great Britain alone, it has been estimated that the quantifiable benefits could be as high as £900m per year from reduced costs of motoring from savings in travel time and distance (12). In the U.S., it has been estimated that about $45 billion could be saved from improved routing (13).

These figures refer to the improvement which would be achieved by the implementation of a static route guidance system, which is based on historic routing information. The autonomous (self-contained) navigation systems (ANS) of the type described earlier fulfil this function. They could be applied to a wide range of vehicles in addition to private cars, including emergency vehicles (fire, police, ambulance) and vehicle fleets (trucks, taxis, service vehicles , etc).

In addition to being a navigation aid, the huge capacity of the CD-ROM offers an unprecedented marketing opportunity for providing a wide variety of other types of information which would be useful to the driver. This could include a directory of motels, restaurants, service stations, police stations, hospitals, etc., and even interesting historical information, for the recreational traveller. Special editions could be developed for the business traveller, which could include such things as a directory of particular types of business establishments in a certain area, etc. Even an "electronic yellow pages" is a possibility. The point is that there there will be a lot of extra space available on the compact disc because it makes little sense to carry around a map of the whole country when so little would be used by the average driver.

Because of the self-contained nature of the ANS, its effectiveness is limited by the fact that the stored electronic map contains only historical information, and is therefore blind to any changes in the road network (static changes such as new construction, road closings, detours, etc.) or its current condition (transient changes due to congestion, accidents etc). Up-dating of stored information can only be achieved by establishing communications links with the outside world. The additional functional capabilities which can be achieved through such communications are illustrated in TABLE IV (14).

Integrated Systems

As can be seen from the Table, a 1-way communications link to the vehicle will provide the capability for semi-dynamic route guidance and hazard warning in addition to static route guidance. These will update the electronic map in the vehicle with recent changes in the historic (static) road network, as well as providing information on prevailing traffic conditions, including warning of emergency conditions exiting in the network. This could be accomplished by area-wide or local digital radio broadcasting. A digital area broadcasting system is, in fact, being proposed for Europe (14) which could interface with vehicles with an ANS as well as with vehicles equipped with a modified radio to receive hazard-warning messages only.

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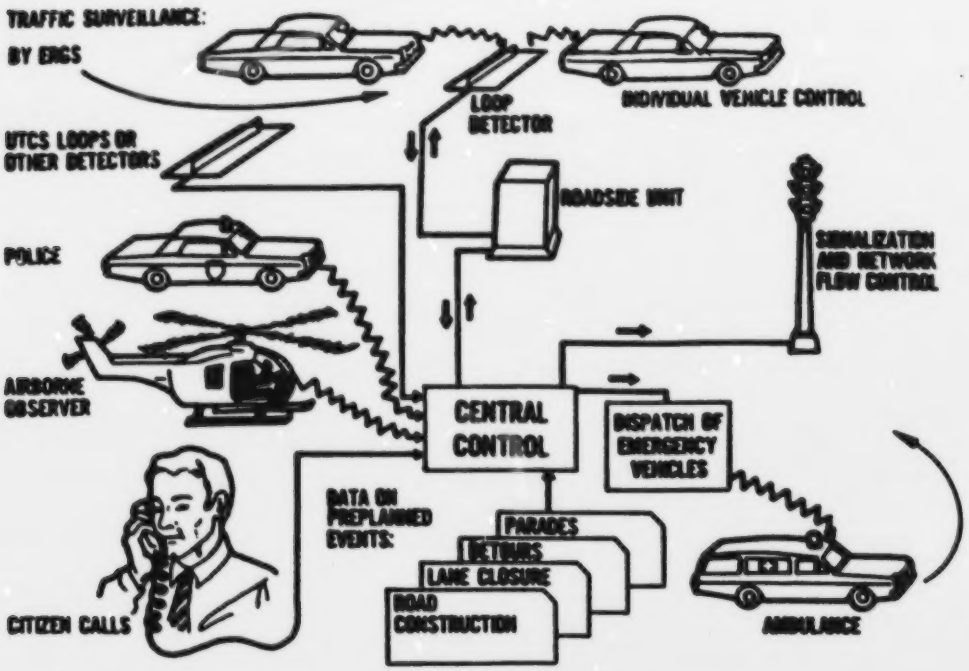

Figure 1 Dynamic Route Guidance

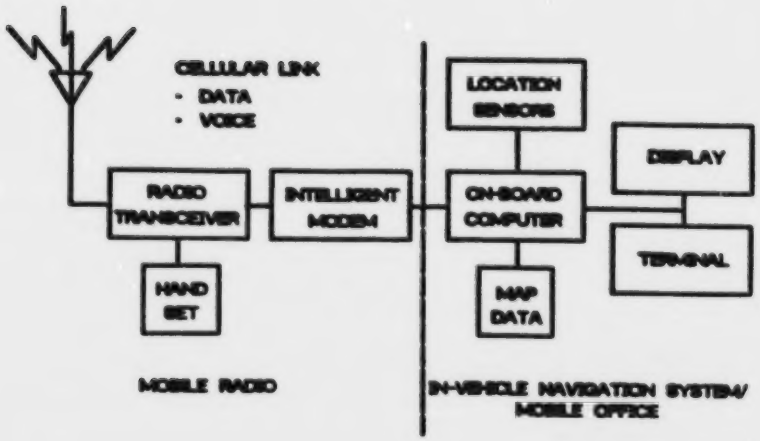

Figure 2 Mobile Information System

FUNCTIONAL CAPABILITY	COMMUNICATIONS None	1-way	2-way
Route Guidance			
* Static	x	x	x
* Semi-dynamic		x	x
* Dynamic			x
Hazard Warning		x	x
Emergency Calls			x
Traffic Management Data Collection			
* General (v,k,q)			x
* Origin-Destin.			x
* Auto. Veh. Loc.			x
* Auto. Veh. I/D			x
* Auto. Incid. Det.			x

TABLE IV Functional Capabilities Resulting From Added Communications

The advantages of 2-way communications are clearly evident in the Table. It opens up the possibility for dynamic route guidance, making emergency calls from the vehicle and collecting information which is critical to traffic management. Dynamic route guidance would provide the individual driver with traffic responsive routing from his origin to his set destination, and sets the stage for real-time integrated urban traffic management. Its scope and potential impact can perhaps best be illustrated by referring to Figure 1, which is taken from the old ERGS Project.

Although a proximity beacon type of system, it shows funtionally the various possibilities. There is also scope for parking management (directing the driver to available spaces) and goods movement (truck routing – just-in-time delivery, etc.). It has been estimated that the additional benefits of dynamic route guidance would be almost as high as for static route guidance alone (13,14).

Mobile cellular radio probably offers the greatest potential for cost-effective 2-way data communications with vehicles equipped with ANS. As the public adopts the idea of the "mobile office", there will be considerable pressure to use cellular radio for the transmission of data as well as voice. In fact, the necessary modems are already beginning to appear on the market. Figure 2 gives a functional block diagram of a future ANS/Mobile Office with a data cellular radio system to form a "Mobile Information System". This concept is the subject of active research in the U.K. (15) and elsewhere.

REFERENCES

1. Gable, D., "Automobile Navigation: Science Fiction Moves Closer to Reality," Electronic Engineering Times, Vol. 296, 1984.

2. French, R. L., "Historical Overview of Automobile Navigation Technology," IEEE Vehicular Technology Conference, Dallas, May, 1986.

3. Tagami, K., Takahashi, T. and Takahashi, F., "'Electro Gyro-Cator', New Inertial Navigation System for Use in Automobiles," SAE Technical Paper No. 830659, 1983.

4. French, R. L., "Autonomous Route Guidance Using Electronic Differential Odometer Dead Reckoning with Vectorized Map-Matching," Proceedings of the U.S. Army Artificial Intelligence and Robotics Symposium, Part II, 1984.

5. General Motors Research Laboratory, "Design for an Experimental Route Guidance System," FHWA Publication PB-197-090/1/2, Nov. 1968.

6. Rosen, D. A., Mammano, F. J. and Favout, R., "An Electronic Route Guidance System for Highway Vehicles," IEEE Transactions on Vehicular Technology, Vol. VT-19, 1970.

7. Cooke, D. F., "Vehicle Navigation Appliances," presented at AutoCarto-VII, Washington, D.C., March 1985.

8. Braegas, P., "Function, Equipment and Field Testing of a Route Guidance and Information System for Drivers (ALI)," IEEE Transactions on Vehicle Technology, Vol. VT-29, No.2, May 1980.

9. Fujii, H., "The CACS Project and Now: Dynamic Route Guidance as the Final Target," presented at the 65th Annual Meeting of the Transportation Research Board, January 1986.

10. Haeussermann, P., "On-Board Computer Systems for Navigation, Orientation and Route Optimization," SAE Technical Paper No. 840485, 1984.

11. von Tomewitsch, R., "ALI-SCOUT – A Universal Guidance and Information System for Road Traffic," Second IEE Conference on Road Traffic Control, April 1986.

12. Jeffery, D. J., "The Potential Benefits of Route Guidance," Transport and Road Research Laboratory, Crowthorne, England, TRRL Rep. 997, 1981.

13. King, F G., "Potential Benefits of Route Guidance," presented 65th Annual Meeting of the Transportation Research Board, Washington, D.C., 1986.

14. EUCO-cost 30 bis, "Road/Vehicle Electronic Communication: Electronic Traffic Aids on Major Roads," Working Group 1 Final Report 205/84, 1984.

15. Walker, John, "The Navigation and Command and Control Aspects of the Mobile Information Systems (MIS) Alvey Demonstration Project," presented at "NAV 85", Royal Institute of Navigation Conference on "Land Navigation and Location for Mobile Applications", York, England, Sept 1985.